Chapter XIII
Qubit Neural Network:
Its Performance and Applications

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ABSTRACT

Recently, quantum neural networks have been explored as one of the candidates for improving the computational efficiency of neural networks. In this chapter, after giving a brief review of quantum computing, the authors introduce our qubit neural network, which is a multi-layered neural network composed of quantum bit neurons. In this description, it is indispensable to use the complex-valued representation, which is based on the concept of quantum bit (qubit). By means of the simulations in solving the parity check problems as a bench mark examination, we show that the computational power of the qubit neural network is superior to that of the conventional complex-valued and real-valued neural networks. Furthermore, the authors explore its applications such as image processing and pattern recognition. Thus they clarify that this model outperforms the conventional neural networks.

INTRODUCTION

Since Shor (1994) proposed a way of factorizing large integers in polynomial time by using a quantum computing algorithm, the study of quantum information science, including quantum communication, quantum cryptography, quantum computer and so on, has been intensified (Nielsen & Chuang,2000). Shor's proposal has not only proved itself to be a milestone in quantum computing, but also created a novel research paradigm of neural computing, i.e., quantum neural computing (Kak, 1995). Since then, various quantum neural computing models have been proposed for the improvement of the computational ability of neural networks so as to expand their applications

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(Peruš, 1996, 2004; Behrman, Nash, Steck, Chandrashekar, & Skinner, 2000; Narayanan, & Menneer, 2000; Ezhov, Nifanova, & Ventura, 2000; Matsui, Takai, & Nishimura, 1998, 2000; Kouda, Matsui, & Nishimura, 2002, 2004; Kouda, Matsui, Nishimura, & Peper, 2005a, 2005b; Mori, Isokawa, Kouda, Matsui, & Nishimura, 2006; Rigui, Nan, & Qiulin, 2006). In this chapter, we introduce a qubit neural network model that is a complex-valued multi-layered neural network composed of quantum bit neurons. We also clarify its learning performance numerically through the benchmark simulations by comparing it to that of the conventional neural networks. The quantum bit (hereafter qubit) neuron model was one that we proposed for the first time, inspired by quantum computation and quantum circuit (see the reference, Matsui, Takai, & Nisimura,1998 in Japanese, 2000 in English) and we also proved that our qubit neural network model (hereafter Qubit NN) is more excellent in learning ability than the conventional real-valued neural network model through solving the image compression problem (Kouda, Matsui, & Nishimura, 2002) and the control problem of inverted pendulum (Kouda, Matsui, Nishimura, & Peper, 2005b). We indicated that these results could be ascribed to the effects of quantum superposition and probabilistic interpretation in the way of applying quantum computing to neural network, in addition to the complex number representation. In the formulation of our model, complex numbers play an essential role, as a qubit is based on the concept of quantum mechanics. Here, to clarify these quantum effects, we show the characteristic features of Qubit NN are superior to those of the old-fashioned conventional complex-valued and/or real-valued neural networks by means of the simulations in solving the parity check problems and the function identification problem as a bench mark examination (see, Kouda, Matsui, Nishimura, & Peper, 2005a). Lastly, we add to the results of the new application examples: the well-known iris data classification and the night vision image processing. Thus we conclude that Qubit NN model outperforms Classical NNs. Here, we call the conventional neural networks Classical NNs according to the traditional comparison: Classical physics versus Quantum physics.

BACKGROUND

Before entering into the discussion of Qubit NN, we introduce its study background. Neural computing and quantum computing, both considered as promising innovative computation models, have attracted much interest from researchers. Neural computing is based on the intellectual and soft information processing of the brain that fuses and harmonizes the analog computation with the digital computation. It has been studied not only in modeling brain functions but also in solving various practical problems in industry such as data classification, pattern recognition, motion control, image processing and so on. Recently, in order to make it a reliable technology of information processing, as well as to expand its applications, Complex-valued, Quaternion-valued and Clifford-algebra neural networks have been explored (Hirose, 2003). We hypothesize that their computational ability can become higher than Real-valued one. This is not a clear problem, but Siegelmann (1999) shows that the computational ability of a neural network depends on the type of numbers utilized as its weight parameters: Integer-valued, Rational-valued and Real-valued type networks are computationally equivalent to finite automata, Turing machine and non-uniform computational models, respectively. Then, we speculate that hyper complex-valued NNs are beyond the computational ability that Turing model has achieved. It is also widely known that the computation based on quantum mechanics has higher computational ability than the Turing model. As for quantum computing, Feynman (1982) raised a question about the feasibility of the computing architectures based on quantum mechanics, and Deutsch (1985) started the study of quantum computing by proposing a computer model that operates according to principles of quantum mechanics—namely, the universal quantum Turing machine was proposed. Deutsch and Jozsa (1992) put forward a prototypical quantum algorithm for the first time, and proved their algorithm was able to speed up the computational processing ability by means of the quantum parallelism. Consequently, the study of quantum computer began to be more accelerated aiming at making clear its computational properties. Bernstein and Vazirani (1993, 1997) showed the existence of universal quantum Turing machines capable of simulating other quantum Turing machines in polynomial time, and Yao (1993) proved that quantum Turing machines are computationally equivalent to quantum circuits. Then, Shor (1994) showed how a solution of a large integer factorization problem in polynomial time is possible in principle by utilizing an algorithm operating on a quantum computer. His algorithm has attracted widespread interest because of the security of modern cryptography. Next, Grover (1996, 1997) discovered a fast quantum algorithm for database search. His

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